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(71) Applicant
The Plessey Company plc (United Kingdom),
Vicarage Lane, Ilford, Essex

(72) Inventors
Brian Lewis,
Ronald George Arnold

(74) Agent and/or Address for Service
K. J. Thorne,
The Plessey Company plc, Intellectual Property Department, Vicarage Lane, Ilford, Essex

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H3U

(54) Surface acoustic wave filters

(57) In SAW filters comprising at least two transducers each having interleaved fingers, reflections from the fingers g,i of the transducers cause SAW's of frequency f propagating on the surface of the filter to be strongly reflected by fingers h, j having a synchronous frequency of f/2. This effect gives rise to large amplitude ripple which is due to interference between directly propagating SAW's and reflected waves. This ripple is reduced by arranging the relative positions of the fingers of one of the transducers to be such that the time taken for a SAW of frequency f generated by a first finger to propagate from the first finger to a second finger differs from the time taken for a SAW of the same frequency to propagate between correponding fingers of the other transducer by ¼ of a period of the SAW.

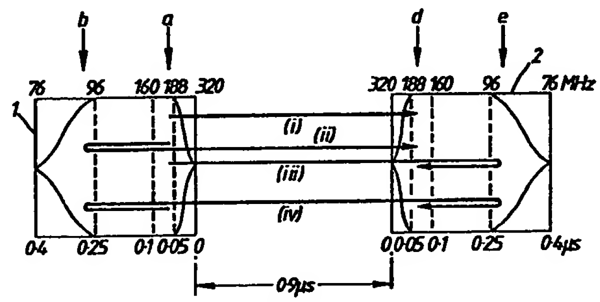

FIG.1.

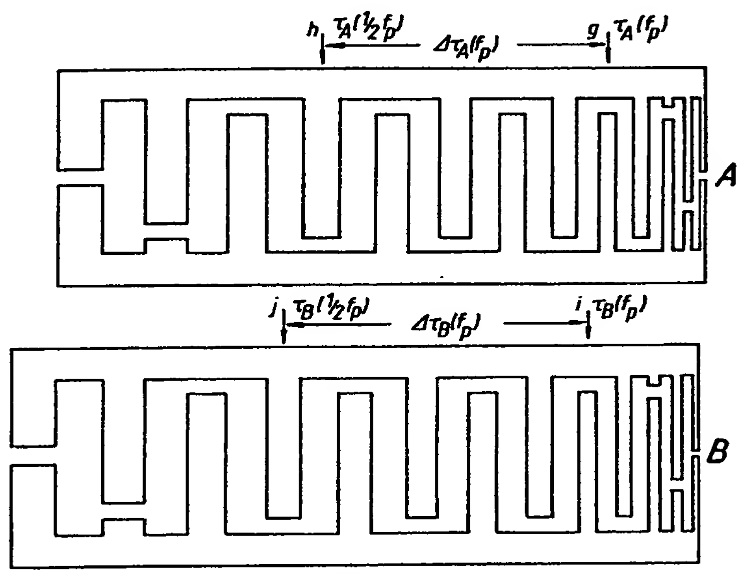

FIG.3.

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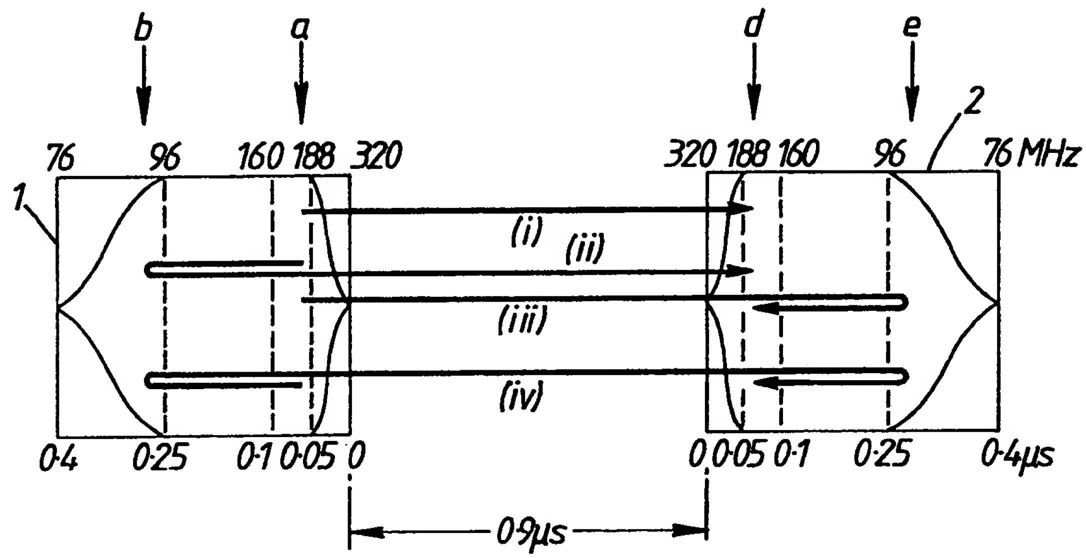

b
a
d
e
2
76
96
160
188
320
320
188
160
96
76 MHz
1
(i)
(ii)
(iii)
(iv)
0·4
0·25
0·1
0·05
0
0
0·05
0·1
0·25
0·4μs
0·9μs

FIG. 1.

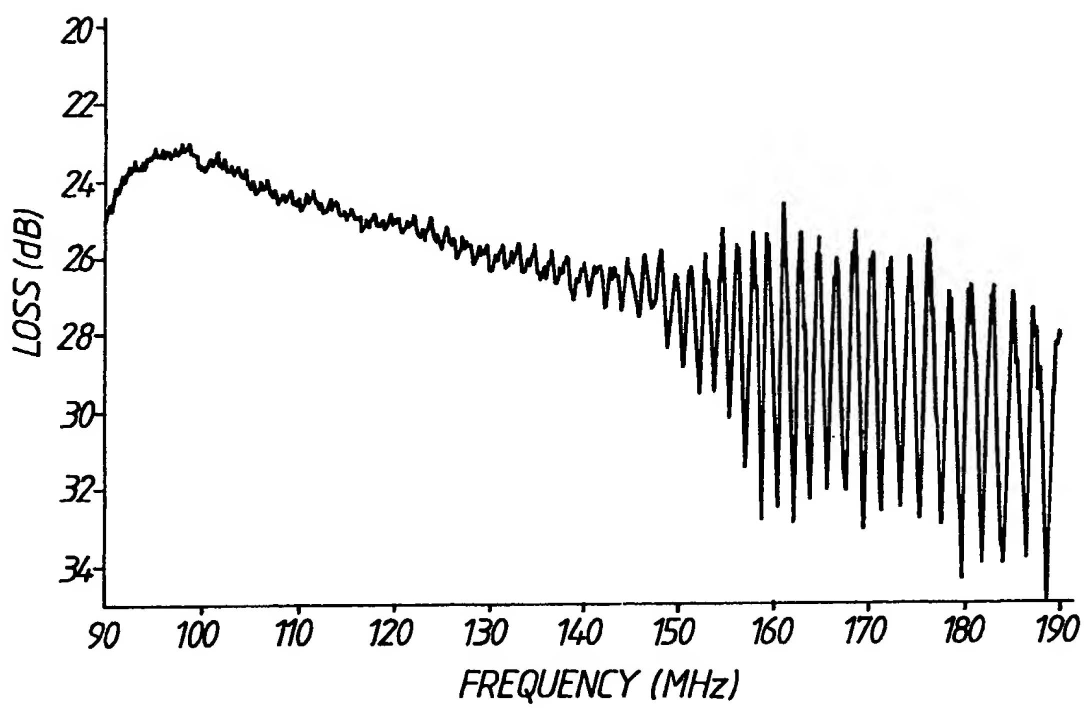
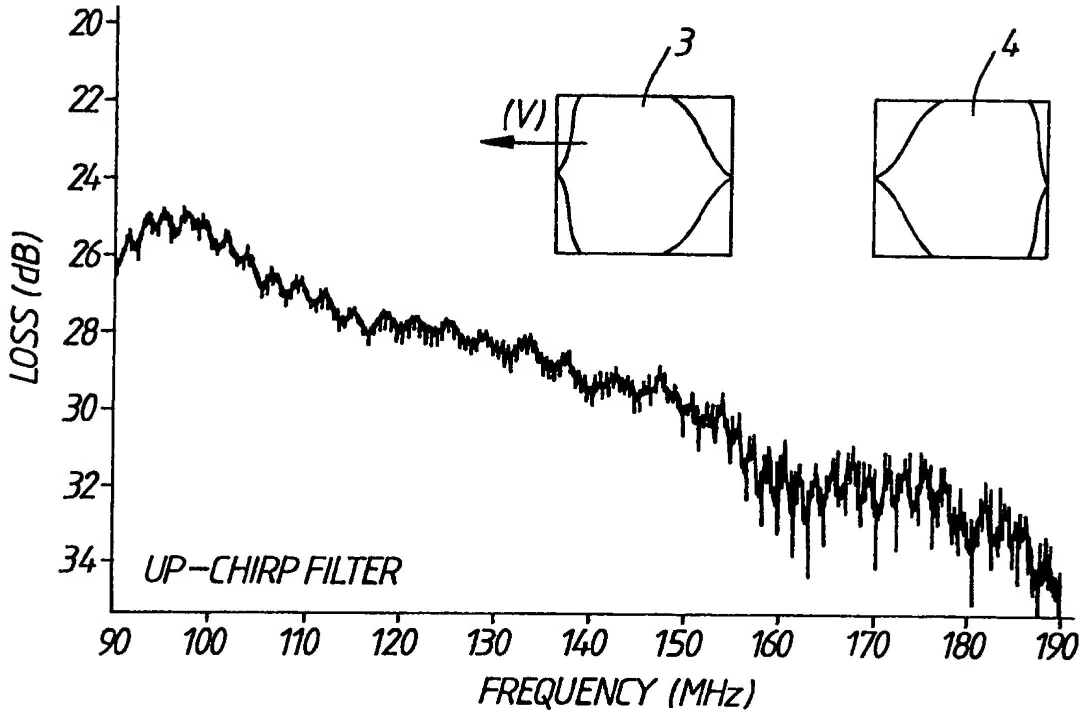
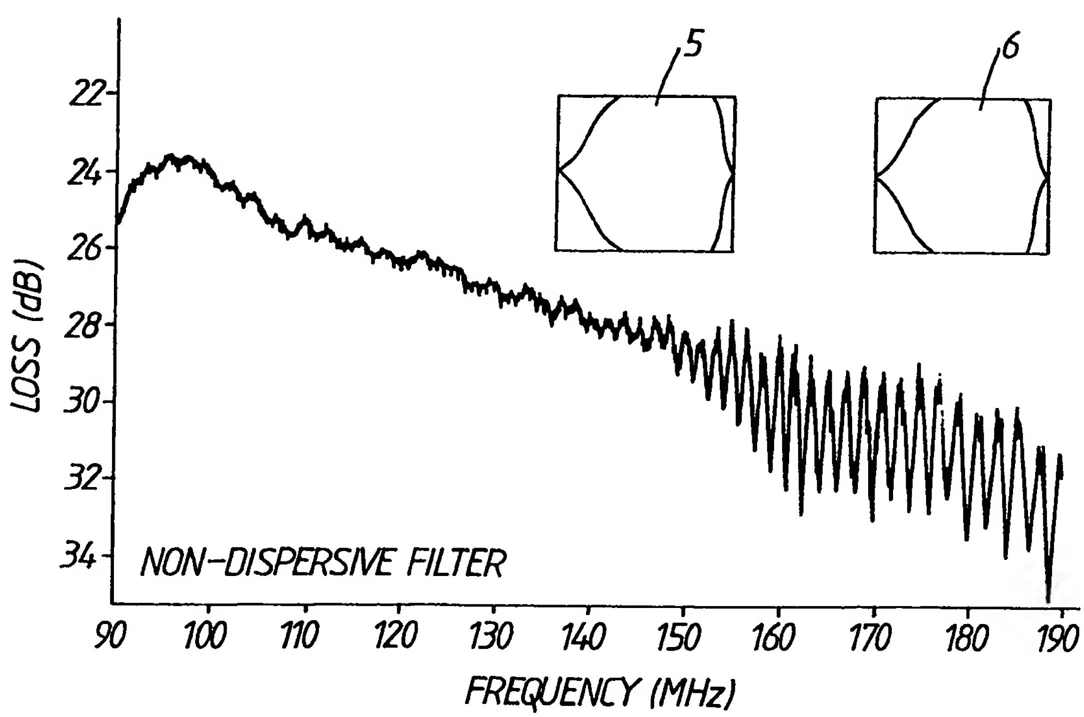

20
22
24
26
28
30
32
34
LOSS (dB)
90
100
110
120
130
140
150
160
170
180
190
FREQUENCY (MHz)

FIG. 2a.



20
22
24
26
28
30
32
34
LOSS (dB)
3
4
(V)
UP-CHIRP FILTER
90
100
110
120
130
140
150
160
170
180
190
FREQUENCY (MHz)

FIG.2b.



22
24
26
28
30
32
34
LOSS (dB)
5
6
NON-DISPERSIVE FILTER
90
100
110
120
130
140
150
160
170
180
190
FREQUENCY (MHz)

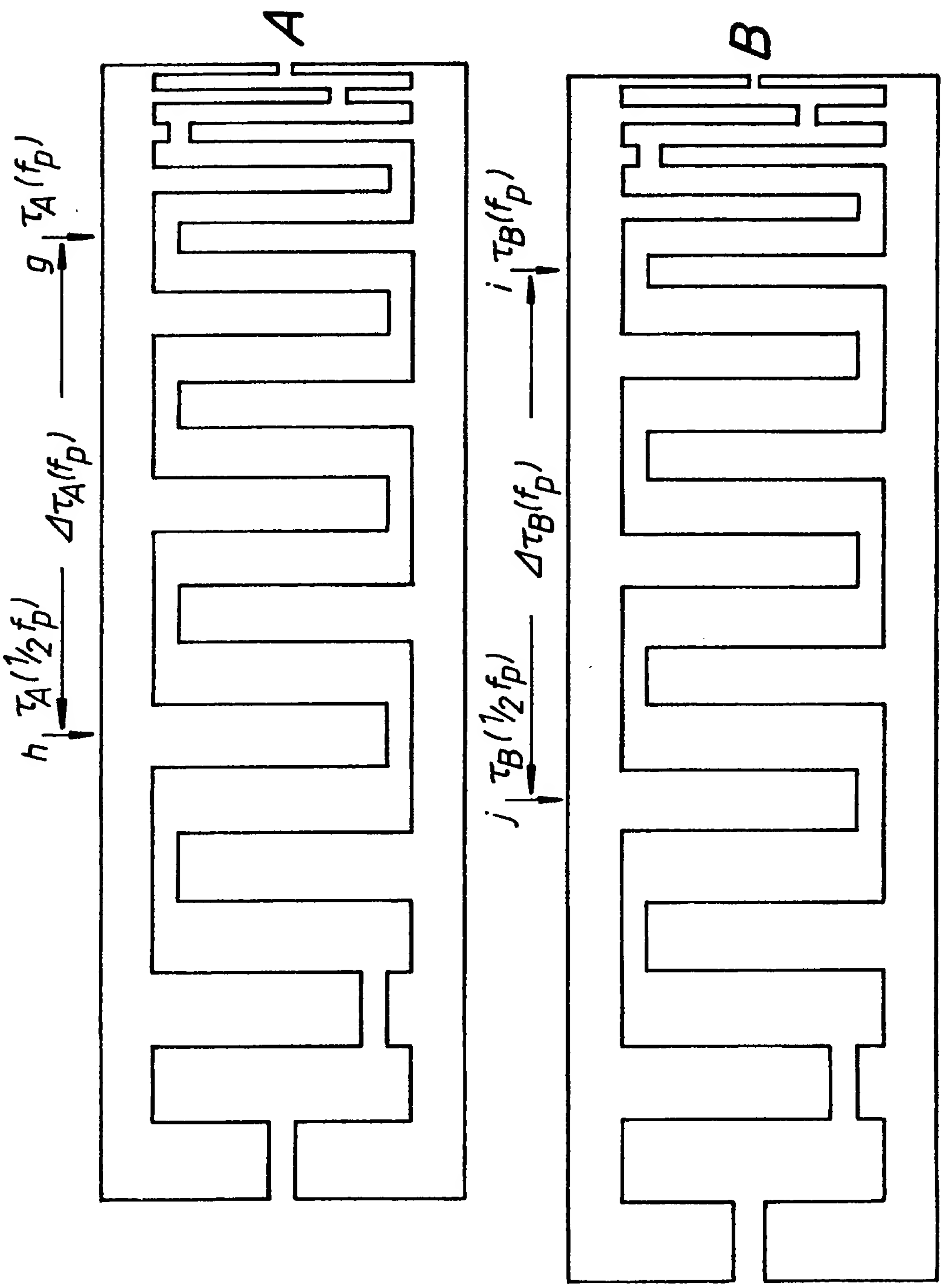

A
B
g
h
i
j
$\tau_A(f_p)$
$\Delta\tau_A(f_p)$
$\tau_A(\frac{1}{2}f_p)$
$\tau_B(f_p)$
$\Delta\tau_B(f_p)$
$\tau_B(\frac{1}{2}f_p)$

FIG. 3.

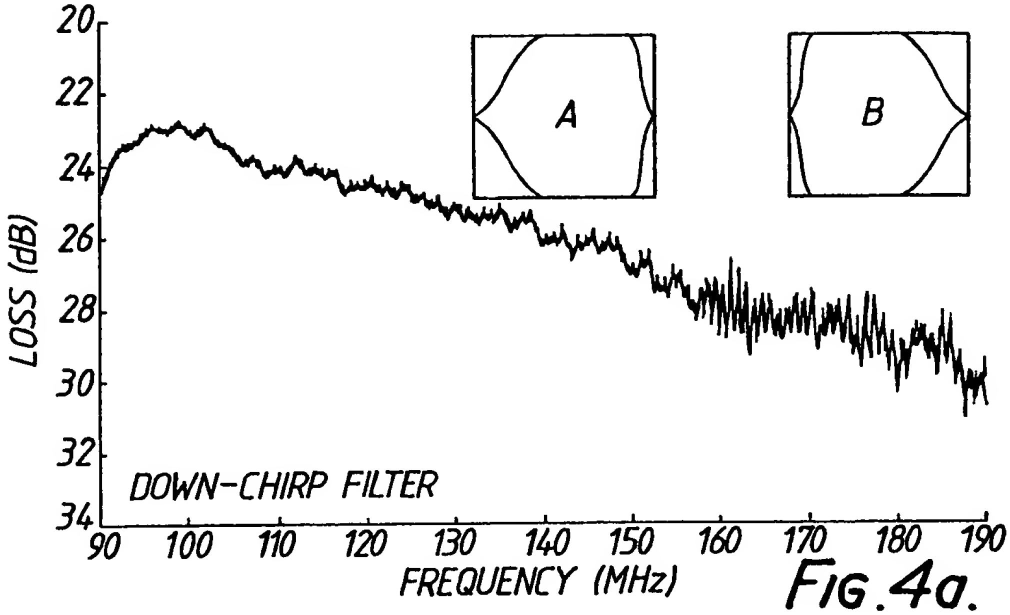

20
22
24
26
28
30
32
34
LOSS (dB)
A
B
DOWN-CHIRP FILTER
90
100
110
120
130
140
150
160
170
180
190
FREQUENCY (MHz)

FIG.4a.

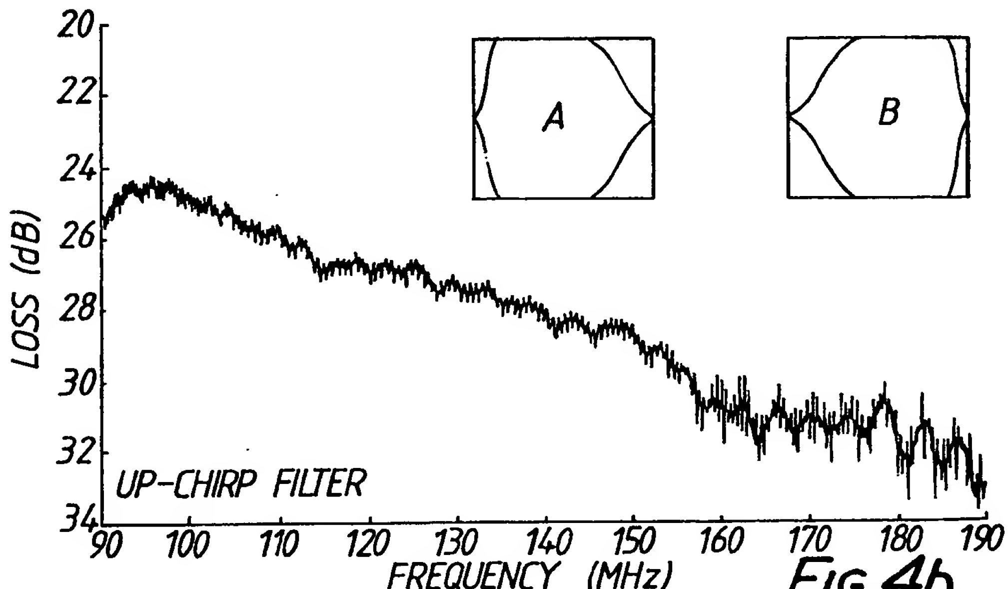
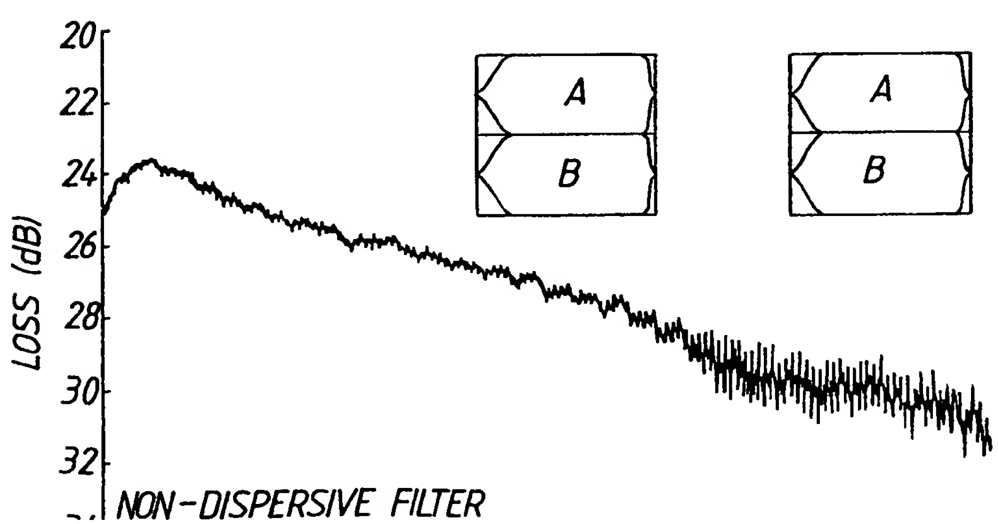
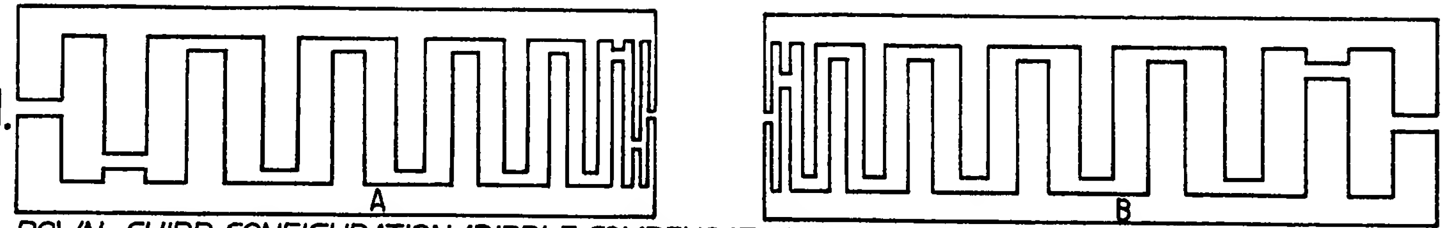

20
22
24
26
28
30
32
34
LOSS (dB)
A
B
UP-CHIRP FILTER
90
100
110
120
130
140
150
160
170
180
190
FREQUENCY (MHz)

FIG.4b.

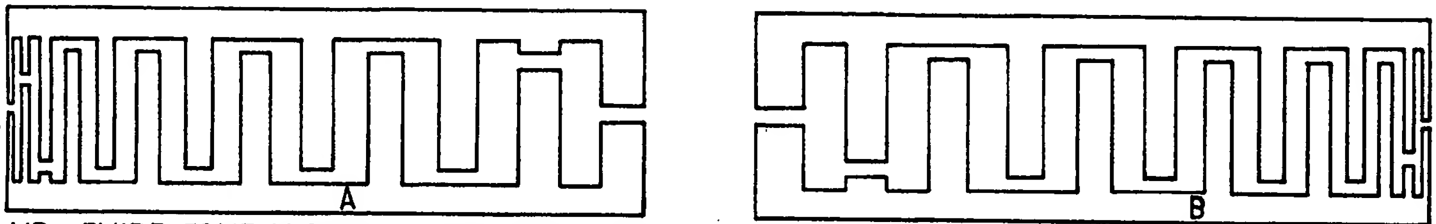

20
22
24
26
28
30
32
LOSS (dB)
A
B
A
B
NON-DISPERSIVE FILTER

5A.



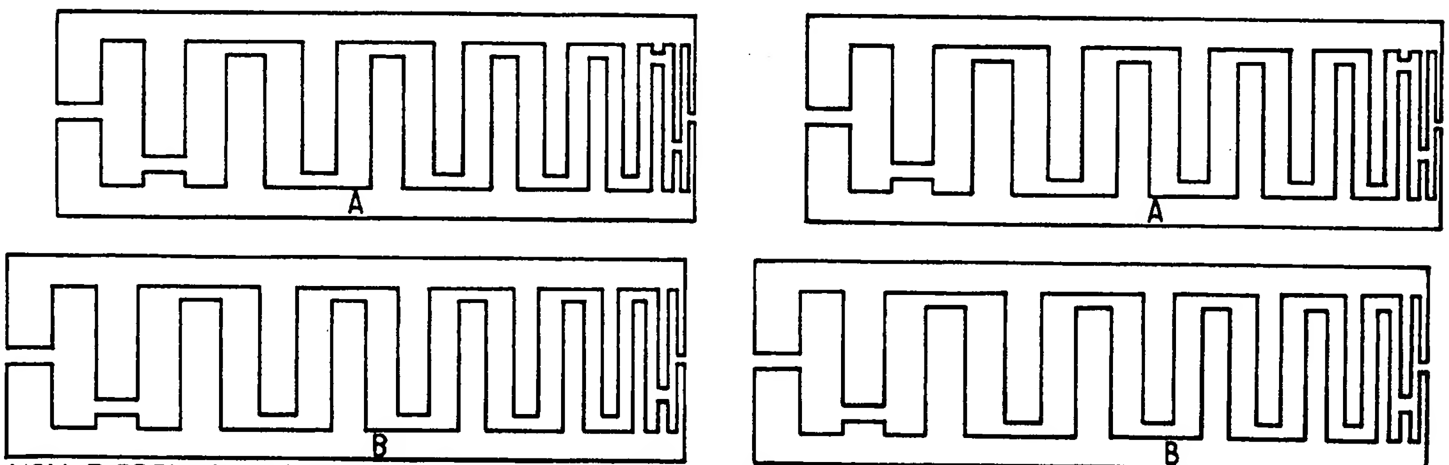
DOWN-CHIRP CONFIGURATION (RIPPLE COMPENSATION) TRANSDUCER A INPUT, B OUTPUT

5B.



UP-CHIRP CONFIGURATION (RIPPLE COMPENSATION) TRANSDUCER A INPUT, B OUTPUT

5C.



NON-DISPERSIVE CONFIGURATION (RIPPLE COMPENSATION) TRANSDUCER A AND B ELECTRICALLY IN PARALLEL FOR INPUT AND OUPUT

SPECIFICATION

Surface acoustic wave filters

This invention relates to surface acoustic wave filters and more particularly to ripple compensation in broadband up-chirp, down-chirp and non-dispersive surface acoustic wave filters.

Surface acoustic wave filters are well known and, for example, comprise a substrate of lithium niobate or other piezoelectric material supporting mutually acoustically coupled input and output transducers each of which comprises interleaved fingers (i.e. electrodes) which largely determine the frequency and bandwidth of the filter. Examples of such surface acoustic wave filters are up-chirp and down-chirp filters which can be used as pulse compression or expansion devices in radar and signal processing, and non-dispersive filters which are used as band pass filters in communication apparatus.

In such surface acoustic wave filters, reflections from the fingers of the transducers cause surface acoustic waves of frequency f propagating on the surface of the filter to be strongly reflected by electrodes having a synchronous frequency of f/2. This effect gives rise to large amplitude ripple, particularly in down-chirp and non-dispersive filters, which is due to interference between directly propagating surface acoustic waves and reflected waves. This effect degrades the performance of the filters.

This ripple may be reduced by making filters on lower coupling materials, such as quartz, which results in fingers having a smaller reflection coefficient. A disadvantage with filters made on such materials is that they have a higher insertion loss and in practice, high coupling materials are considered to be essential for broadband filters. An alternative method of reducing the ripple effect is to use an up-chirp filter in preference to a down-chirp filter since the ripple is smaller in an up-chirp filter. This method is disadvantageous since up-chirp filters have higher insertion losses due to directionality and bulk-wave conversion than down-chirp filters.

It is possible to avoid the ripple caused by reflections within a surface acoustic wave filter by limiting the bandwidth of the filter so that the ratio of the frequency of the highest synchronous frequency fingers to the lowest is less than 2:1. The disadvantage with such a limitation however is that the bandwidth of the filter is necessarily limited.

It is an aim of the present invention to reduce or to eliminate ripple in up-chirp, downchirp and non-dispersive filters thereby to provide a surface acoustic wave filter affording a wide bandwidth and reduced amplitude ripple.

According to the present invention there is provided a surface acoustic wave filter comprising two transducers each of which includes a set of interdigitated fingers having a first finger which represents a location of generation or reception of a surface acoustic wave having a frequency f, a second finger spaced apart from the first finger, which second finger represents a location of generation or reception of a surface acoustic wave having a frequency f/2, wherein each transducer is characterised by a time path difference defined as the time taken for the surface acoustic wave generated at the first finger to propagate from the first finger to the second finger, the spacing between the first and second fingers of one of the two transducers being arranged to differ from the spacing between corresponding first and second fingers of the other of the two transducers such that the time path difference which characterises the said one transducer differs from the time path difference which characterises the other of the two transducers by substantially one quarter of the duration of one cycle of the surface acoustic wave of frequency f.

The surface acoustic wave filter may consist of two transducers only.

The transducers may be arranged so that the surface acoustic wave filter is a down-chirp filter or, alternatively, they may be arranged such that the surface acoustic wave filter is an up-chirp filter.

The surface acoustic wave filter may comprise two pairs of transducers, wherein each pair includes a transducer corresponding to said one transducer and a transducer corresponding to said another transducer.

The invention will now be further described by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a schematic diagram of a down-chirp filter illustrating surface acoustic wave propagation for a wave having a particular frequency;

Figure 2a is a graph showing insertion loss in the down-chirp filter of Figure 1;

Figure 2b is a graph showing insertion loss in a known up-chirp filter;

Figure 2c is a graph showing insertion loss in a known non-dispersive filter;

Figure 3 is a diagram showing a pair of transducers having different time path differences for a particular freqency f, in accordance with the present invention;

Figure 4a is a graph showing insertion losses in a down-chirp filter embodying the present invention;

Figure 4b is a graph showing insertion losses in an up-chirp filter embodying the present invention;

Figure 4c is a graph showing insertion losses in a non-dispersive filter embodying the present invention; and

Figures 5a to 5c respectively show diagrams of the disposition of the transducers of the filters of Fig-

comprises a generating transducer 1 which is identical in construction to a receiving transducer 2, and both transducers are on a piezoelectric substrate (not shown). Each of the transducers 1 and 2 comprise interdigitated fingers (not shown) which define the bandwidth of the filter. As can be seen from Figure 1, the transducers 1 and 2 are disposed with respect to one another so that fingers which serve for the generation and reception of high frequency surface acoustic waves are closest together and fingers which serve for the generation and reception of low frequency surface acoustic waves are farthest apart.

Propagation of a surface acoustic wave having, for example, a frequency f_p of 180 MHz across the surface of the filter will now be considered. This surface acoustic wave is generated at fingers of the transducer 1 which are synchronous at f_p equal to 180 MHz, which fingers are located at 'a' in Figure 1. Propagation of the 180 MHz surface acoustic wave is bidirectional, one direction being forwards towards the receiving transducer 2 (designated by an arrow (i)), and the other being backwards towards the low frequency end of the transducer 1 where a significant proportion is reflected by fingers at a position 'b' which are synchronous at a frequency of 90 MHz, i.e. one half of the 180 MHz surface acoustic wave. This reflected surface acoustic wave is designated by an arrow (ii) in Figure 1.

The 180 MHz surface acoustic wave designated by the arrow (i) propagates into the receiving transducer 2. A proportion is received by the fingers at a position 'd' which represents reception of surface acoustic waves having a frequency of 180 MHz. The remainder of the surface acoustic wave continues to propagate through the transducer 2 towards the low frequency end until it reaches a point 'e', where a significant proportion is reflected by fingers having a synchronous frequency of a half f_p (90 MHz). An arrow (iii) illustrates the path of this reflected surface acoustic wave from its point of origin in transducer 1 to its arrival at the point 'd' after reflection at the point 'e' in the transducer 2.

Referring now to Figure 2a, insertion loss of the down-chirp filter of Figure 1 is graphically shown for surface acoustic waves having frequencies of 90 to 190 MHz. A 7 dB linear variation occurs over the range 96 to 140 MHz, with a 27 dB insertion loss at 140 MHz. Small amplitude ripple occurs at low frequencies, increasing to 1dB peak to peak at 140 MHz and to 8 dB above 160 MHz. It can be seen from Figure 2a that the increase in ripple begins to occur at a frequency which is about twice the synchronous frequency of the lowest frequency fingers (i.e. twice 76 MHz). The ripple period, for each frequency, is equal to the inverse of twice the transit time of a surface acoustic wave propagating between fingers synchronous at f_p and $\frac{1}{2}f_p$.

The ripple is due to interference between the forward generated wave propagating from a to d (arrow (i)), the forward generated surface acoustic wave after reflection at the point 'e' (arrow (iii)) and the backward wave after reflection by fingers at the point 'b' (see arrow (ii)).

An arrow (iv) represents higher order reflections which occur in the filter. Such reflections are of relatively low amplitude compared with the reflections giving rise to the ripple described above.

Figures 2b and 2c respectively show insertion loss due to ripple for an up-chirp filter and a non-dispersive filter. The up-chirp filter comprises a generating transducer 3 and an identical receiving transducer 4 disposed as shown in the inset of Figure 2b, that is, with the low frequency fingers closest together and the high frequency fingers farthest apart. The up-chirp filter has a 2 dB larger insertion loss than the down-chirp filter and a ripple amplitude 1dB peak to peak. Hence, it can be seen that although insertion loss due to ripple is less in an up-chirp filter than in a down-chirp filter, the overall insertion loss is higher.

The non-dispersive filter comprises a generating transducer 5 and an identical receiving transducer 6. In this case, the transducers 5 and 6 are disposed as shown in the inset of Figure 2c. The insertion loss is larger by 1dB at 140 MHz, and the ripple amplitude is halved as compared with the down-chirp filter.

Referring now to Figure 3, a pair of transducers labelled A and B respectively are shown. In order to simplify explanation of the operation of the transducers A and B, generation, reception and reflection of surface acoustic waves in each of the transducers A and B shall be deemed as occurring at specific rather than distributed locations. In the transducer A, a surface acoustic wave of frequency f_j is generated at a first finger 'g' at time-position t_A (f_p) (where time-position $t_A(f_p) = x_A(f_p)/V$ where x_A is the finger position and V is the propagation velocity of the surface acoustic wave). This surface acoustic wave propagates across the surface of the transducer A and is reflected at a second finger 'h' having a synchronous frequency of $\frac{1}{2}f_p$ at a time- position $t_A(\frac{1}{2}f_p)$. Hence, the transducer A is characterised by a time path difference which is defined by the time taken for the surface acoustic wave generated at the first finger to propagate from the first finger 'g' to the second finger 'h'. This time path difference is denoted by $t_A(f_p)$ which is given by:

$$\Delta t_A(f_p) = t_A(f_p) - t_A(\tfrac{1}{2}f_p) \qquad (1)$$

Similarly, the time path difference for a surface acoustic wave of frequency f_j in the transducer B is denoted by $\Delta t_B(f_p)$ which is given by:

$$\Delta t_B(f_p) = t_B(f_p) - t_B(\tfrac{1}{2}f_p) \qquad (2)$$

finger 'g' in the transducer A) to propagate from the first finger 'i' to a second finger 'j' (which second finger 'j' corresponds to the second finger 'h' in the transducer A) differs from Δ_A (f_p) by a quarter of a period τ of the surface acoustic wave having the frequency f_p. With this objective, the transducer B has the time-positions t_B (f) of fingers with synchronous frequency f displaced from the time-positions t_A (f) of the corresponding fingers of the transducer A by $\frac{1}{4}\tau(f)$, where $\tau(f) = 1/f$. That is, such that for ;$f = fp$:

$$\left.\begin{array}{l} t_B(f_p) = t_A(f_p) - \tfrac{1}{4}\tau(f_p). \\ \text{and for } f = \tfrac{1}{2}f_p: \\ t_B(\tfrac{1}{2}f_p) = t_A(\tfrac{1}{2}f_p) - \tfrac{1}{4}\tau;(\tfrac{1}{2}f_p). \end{array}\right\} \qquad (3)$$

Hence, the time path difference Δ t_B (f_p) is given by:

$$\Delta t_B(f_p) = t_A(f_p) - \tfrac{1}{4}\tau(f_p) - t_A(\tfrac{1}{2}f_p) + \tfrac{1}{4}\tau(\tfrac{1}{2}f_p);$$

$$\tau(\tfrac{1}{2}f_p) = 2\tau(f_p),$$

$$\therefore \Delta t_B(f_p) = \Delta t_A(f_p) + \tfrac{1}{4}\tau(f_p) \qquad (4)$$

It can be seen from equation (4), that for all values of f_p, the time path differences Δt_B and Δt_A differ by one quarter of a period. It follows that when the transducer A and B are disposed with respect to one another so that a down-chirp filter is formed, the surface acoustic waves represented by the arrows (ii) and (iii) will destructively interfere at all frequencies f_p because the reflection path time difference is

$$2(\Delta t_B(f_p) - \Delta t_A(f_p)) = \tfrac{1}{2}\tau(f_p) \qquad (5)$$

These waves therefore cancel, and do not interfere with the surface acoustic wave which corresponds to arrow (i) in Figure 1. When pairs of transducers designed in accordance with the transducers A and B are used in a surface acoustic wave filter, an overall ripple free filter response can be obtained.

The density of the fingers in the transducer A are such that there is one electrode per half wavelength across the bandwidth of the transducer. It can be seen from Figure 3 that by displacing to the left each finger of the transducer A by a distance corresponding to one quarter of the period of the frequency represented by that finger, the transducer B is constructed and has fingers which are located at the positions of the spaces between the fingers of the transducer A.

The fact that the relative positions of the fingers of the transducer A differ from the positions of the fingers of the transducer B, only slightly affects the dispersion time and/ or bandedge frequencies of the filter.

One method of positioning the fingers of the transducer B in accordance with the present invention, once having positioned the fingers of the transducer A, is to locate the centre of each finger of the transducer B midway between the positions of the centres of adjacent corresponding fingers of the transducer A. Alternatively, corresponding fingers of the transducer B may be positioned midway between closest edges of adjacent corresponding fingers of the transducer A.

In practice, the width and separation of the fingers vary progressively in the above described transducers, and therefore, these methods do not necessarily provide an exact solution as dictated by equation (3). However, this does not detract from the reduction or elimination of ripple in embodiments of the present invention. In any case the exact positioning of the fingers of both transducers depends on the precise algorithm used to determine the finger positions and the widths of the fingers.

Figure 4a is a graph showing insertion losses of a down-chirp filter comprising two transducers A and B in accordance with the present invention which are disposed with respect to one another as illustrated in the inset part of Figure 4a, that is, with the high frequency synchronous fingers of the transducers A and B closest together. As can be seen from Figure 4a, the insertion loss due to ripple caused by reflecting surface acoustic waves is significantly reduced. Surface acoustic waves represented by the arrows (ii) and (iii) of Figure 1 destructively interfere and so cancel, leaving ripple resulting from double reflections represented by arrow (iv) to interfere with the direct forward surface acoustic wave represented by the arrow (i).

Figure 4b shows insertion losses in an up-chirp filter embodying the present invention. Again, even though the ripple amplitude is smaller in an up-chirp filter compared with the down-chirp filters, a reduction in insertion loss is obtained.

Figure 4c shows insertion loss in a non-dispersive filter, in this case, as indicated in the inset part of Figure 4c, both transmitting and receiving transducers comprise transducers A and B, electrically and acoustically in parallel. The non-dispersive A - A delay is the same as the B - B delay, and the response is the sum of the A - A, B - B responses which have anti-phase ripple. Therefore there is a reduction in ripple caused by cancellation in the summed response.

trodes per wavelength at synchronism, the present invention is not limited to such and may be applied to split finger transducers with four electrodes per wavelength at synchronism.

CLAIMS

1. A surface acoustic wave filter comprising two transducers each of which includes a set of interdigitated fingers having a first finger which represents a location of generation or reception of a surface acoustic wave having a frequency f, a second finger spaced apart from the first finger, which second finger represents a location of generation or reception of a surface acoustic wave having a frequency f/2, wherein each transducer is characterised by a time path difference defined as the time taken for the surface acoustic wave generated at the first finger to propagate from the first finger to the second finger, the spacing between the first and second fingers of one of the two transducers being arranged to differ from the spacing between corresponding first and second fingers of the other of the two transducers such that the time path difference which characterises the said one transducer differs from the time path difference which characterises the other of the two transducers by substantially one quarter of the duration of one cycle of the surface acoustic wave of frequency f.

2. A surface acoustic wave filter according to claim 1 consisting of two transducers only.

3. A down-chirp filter comprising a surface acoustic wave filter according to claim 1 or claim 2.

4. An up-chirp filter comprising a surface acoustic wave filter according to claim 1 or claim 2.

5. A non-dispersive filter comprising a surface acoustic wave filter according to claim 1 having two pairs of transducers, wherein each pair includes a transducer corresponding to said one transducer and a transducer corresponding to said another transducer.

6. An up-chirp filter comprising a surface acoustic wave filter according to claim 1 having two pairs of transducers, wherein each pair includes a transducer corresponding to said one transducer and a transducer corresponding to said another transducer.

7. A down-chirp filter comprising a surface acoustic wave filter according to claim 1 having two pairs of transducers, wherein each pair includes a transducer corresponding to said one transducer and a transducer corresponding to said another transducer.

8. A surface acoustic wave filter substantially as herein before described with reference to Figures 3 and 5a to 5c of the accompanying drawings.

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